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Metallic materials — Fatigue testing — Axial force-controlled method

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 5, *Fatigue testing*.

This third edition cancels and replaces the second edition (ISO 1099:2006), which has been technically revised.

It shall be noted that this document does not address safety or health concerns, should such issues exist, that may be associated with its use or application. The user of this document has the sole responsibility to establish any appropriate safety and health concerns as well as to determine the applicability of any national or local regulatory limitations regarding the use of this document.

Introduction

This document is intended to provide guidance for conducting axial, constant-amplitude, force-controlled, cyclic fatigue tests on specimens of a metal for the sake of generating fatigue-life data (i.e. stress vs. cycles to failure) for material characterization.

Nominally identical specimens are mounted in an axial force-type fatigue-testing machine and subjected to the required cyclic force conditions that introduce any one of the types of cyclic stress as illustrated in Figure 1. The test waveform should be of constant amplitude and sinusoidal unless otherwise specified.

The force being applied to the specimen is along the longitudinal axis passing through the centroid of each cross-section. The test is continued until the specimen fails or until a predetermined number of stress cycles have been exceeded (See Clauses 4 and 13). Tests are typically conducted at ambient temperature (ideally between 10 °C to 35 °C).

NOTE The results of a fatigue test can be affected by atmospheric conditions and where controlled conditions are required, ISO 554:1976, 2.1 applies.

Metallic materials — Fatigue testing — Axial force-controlled method

1 Scope

This document specifies the conditions for conducting axial, constant-amplitude, force-controlled, fatigue tests at ambient temperature on metallic specimens, without deliberately introduced stress concentrations. The object of testing while employing this document is to provide fatigue information, such as the relation between applied stress and number of cycles to failure for a given material condition, such as hardness and microstructure, at various stress ratios.

While the form, preparation and testing of specimens of circular and rectangular cross-section are described, component testing and other specialized forms of testing are not included in this document.

NOTE 1 Fatigue tests on notched specimens are not covered by this document since the shape and size of notched test pieces have not been standardized. However, fatigue-test procedures described in this document can be applied to fatigue tests of such notched specimens.

NOTE 2 Throughout this document, the engineering stress is employed. Engineering stress is defined as the quotient of the axially applied force to the cross-sectional area of the test specimen, S = Force/Area, at the test temperature.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4965-1, *Metallic materials — Dynamic force calibration for uniaxial fatigue testing — Part 1: Testing systems*

ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines – Verification and calibration of the force-measuring system*

ISO 23788, *Metallic materials — Verification of the alignment of fatigue testing machines*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
test specimen diameter
d
diametric distance or width of the specimen or test piece where the stress is at a maximum

3.2
grip diameter
D
diameter of the specimen at grip end

3.3
thickness of test section
t
thickness of reduced section of rectangular test specimen

3.4
width of test section
w
width of reduced section of rectangular test specimen

3.5
parallel length
L_p
length in the gauge test section of a specimen or test piece that has equal test diameter or test width and is parallel

3.6
specimen length
L_z
overall length of test specimen

3.7
fillet radius
r
radius between the parallel length and the grip end of test specimen

Note 1 to entry: The curve need not be a true arc of a circle over the whole of the distance between the end of the parallel length and the start of the grip end.

3.8
maximum stress
S_{max}
greatest algebraic value of stress in a stress cycle

Note 1 to entry: See Figure 2.

3.9
mean stress
S_m
one-half the algebraic sum of the maximum stress and the minimum stress in a stress cycle

Note 1 to entry: See Figure 2.

3.10
minimum stress
S_{min}
least algebraic value of stress in a stress cycle

Note 1 to entry: See Figure 2.

3.11
stress amplitude
S_a
one-half the algebraic difference between the maximum stress and the minimum stress

Note 1 to entry: See Figure 2.

3.12
stress range
ΔS
algebraic difference between the maximum and minimum stress

$$\Delta S = S_{max} - S_{min}$$

Note 1 to entry: See Figure 2.

3.13
stress ratio
R_S
ratio of minimum to maximum stress during any single cycle of fatigue operation

$$R_S = S_{min}/S_{max}$$

Note 1 to entry: See Figure 2.

3.14
stress cycle
variation of stress with time, repeated periodically and identically

Note 1 to entry: See Figure 2.

3.15
number of cycles
N
number of smallest segments of the force-time, stress-time, etc., function that is repeated periodically

3.16
fatigue life
N_f
number of applied cycles to achieve a defined failure criterion

3.17
fatigue strength at *N* cycles
S_N
value of the stress amplitude at a stated stress ratio under which the specimen would have a life of *N* cycles

4 Test plan

4.1 General outline

Before commencing testing, the following shall be agreed by the parties concerned, unless specified otherwise in the relevant product standard:

a) the form of specimen to be used (see 5.1);

b) the *R*-ratio(s) to be used;

c) the objective of the tests, i.e. which of the following is to be determined:

— the fatigue life at a specified stress amplitude;

— the fatigue strength at a specified life;

— a full Wöhler or *S*-*N* curve.

d) the number of specimens to be tested and the testing sequence;

e) the number of cycles at which a test on an un-failed specimen shall be terminated;

f) the testing temperature if different from the requirements given in 5.2.

In the light of recent research, it is of importance to note that metals generally do not exhibit a “fatigue limit” *per se*, that is, a stress below which the metal will endure an “infinite number of cycles”. Typically, the “plateau(s)” in stress-life are referred to as the conventional “fatigue limit(s)”, but failures below these levels have been reported and do occur. See, for example, References [6] to[9].

4.2 Presentation of fatigue results

4.2.1 General

The design of the investigation and the use to be made of the results, govern the choice of the most suitable method of presenting the results from the many available, graphically and otherwise. The results of fatigue tests are usually presented graphically. In reporting fatigue data, the test conditions should be clearly defined. In addition to graphical presentations, tabulated numerical data are desirable where the presentation format permits.

4.2.2 Wöhler or *S*-*N* curve

The most general method of presenting the results graphically is to plot the number of cycles to failure, *N*, as abscissa and the values of stress amplitude or, depending on the type of stress cycle, those of any other stress, as ordinate. The curve drawn smoothly as an approximate middle line through the experimental points is called a Wöhler or *S*-*N* curve. A logarithmic scale is used for the number of cycles and the choice of whether a linear or logarithmic scale is used for the stress axis lies with the experimenter. Individual curves are plotted for each set of tests for each *R*-ratio. Experimental results are usually plotted on the same figure. An example of these graphical representations is shown in Figure 3, where a linear stress scale is used.

4.2.3 Mean stress diagrams

The fatigue strengths derived from the Wöhler or *S*-*N* curve are plotted in fatigue strength diagrams as constant life lines. The results can be represented by a graph giving directly, for particular fatigue lives, the stress amplitude against the mean stress, as shown in Figure 4; or by plotting the maximum and minimum stresses against the mean stress, as shown in Figure 5; or by plotting the maximum stress against the minimum stress, as shown in Figure 6. Experimental results may be plotted on the same figure.

5 Shape and size of specimen

5.1 Form of specimens

Generally, a specimen having a fully machined test section is of the type shown in Figure 7 for a smooth cylindrical-type gauge section.

The specimens may be of the following:

— circular cross-section with tangentially blending fillets between the test section and the ends, or with a continuous radius between the ends (i.e. “hourglass” specimen);

— rectangular cross-section of uniform thickness over the test section with tangentially blending fillets between the test section and the gripped ends (see Figure 8).

Specimens commonly known as “hourglass” specimens may be employed for testing with caution. In such specimens, there is a continuous radius between grip ends with a minimum diameter or width of the test section centrally located between these ends for cylindrical and flat specimens respectively. Unlike a smooth, constant diameter or width, gauge section where a volume of material is equally under stress, the hourglass specimen permits sampling only of a thin planar element of material at the minimum cross section. Thus, the fatigue results produced may not represent the response of the bulk material where, particularly in the long-life fatigue regime, inclusions govern behaviour in high hardness metals and there is a duality in crack initiation from surface to subsurface[9]. In fact, such results may be non-conservative particularly in the longer life regime where the largest micro discontinuity may not lie in the planar section of greatest stress.

It is important to note that for specimens of rectangular cross-section, it may be necessary to reduce the test section in both width and thickness. If this is necessary, then blending fillets will be required in both the width and thickness directions. Also, for a rectangular-section specimen, where it is desired to take account of the surface condition in which the metal will be used in actual application, then at least one surface of the test section of the test piece should remain unmachined. It is often the case, for fatigue tests conducted using a rectangular-section piece, that the results are not always comparable to those determined on cylindrical specimens because of the difficulty in obtaining an adequate surface finish or because fatigue cracks initiate preferentially at the corner(s) of the rectangular test piece.

5.2 Specimen temperature measurement

Tests are typically conducted at ambient temperature (ideally between 10 °C to 35 °C). For tests conducted at non-ambient temperatures, the specimen temperature shall be fully documented and measured using thermocouples or other appropriate devices in contact with the specimen surface, be accurate to within ±2 °C.

6 Geometry

6.1 Bars and flat sheets >5 mm thick

The gauge portion of the specimen in a fatigue test represents a volume element of the material under study. This implies the geometry of the specimen shall not affect the use of the test results.

This geometry shall fulfil the following conditions:

— provide a uniform cylindrical gauge portion;

— minimize the risk of buckling in compression to avoid failure initiation at the transition radius;

— provide a uniform stress (strain) distribution over the whole gauge portion.

There shall be no undercutting due to machining of the parallel length at the transition radii or elsewhere on the gauge section. This feature may be checked with an optical comparator at reasonable magnification (i.e. ~10 to 25X) to assure this is true.

Taking into account these requirements, the experience gained by a large number of laboratories and the results of calculations taken from different types of specimens (see References [10] to [19]), the following geometric dimensions (see Figure 7) are recommended:

a) diameter of cylindrical gauge length: $5\ \text{mm} \le d \le 10\ \text{mm}$

b) parallel length: $L_p \ge 2d$

c) transition radius (from parallel length to grip end): $r \ge 2d$

d) diameter of grip end: $D \ge 2d$

e) length of reduced section: $L_r \le 8d$

Other geometric cross-sections and gauge lengths may be used for specimens provided that uniform distribution of stress in the gauge length is ensured.

Recommended end connections are as follows:

— smooth cylindrical connection (with hydraulic jaws);

— button-end connection.

The test fixture should locate the specimen, provide axial alignment and exclude backlash. Design of the test fixture will depend on the specimen end details. A number of examples are given in Figure 9.

Designs of fatigue specimens in which alignment may depend on screw threads are not recommended.

6.2 Flat sheets

6.2.1 General

In general, the considerations discussed in the preceding paragraphs also apply to tests on the above products. However, these tests require specific geometries and fixtures in order to avoid problems of buckling.

Because low forces are generally applied, more sensitive force transducers than usual may be required. The gripping system may necessitate the use of flat mechanical or hydraulic jaws. However, with the latter type of assembly it is difficult to ensure correct alignment.

In general, the width of the specimen is reduced in the gauge length to avoid failures at the specimen/grip interface or within the grips. In some applications, it might be necessary to add end tabs to increase the grip end thickness as well as to avoid failure in the grips (see Figure 10).

In the case of flat specimens located in grips with parallel-sided jaws, care should be taken to make sure they are centrally aligned within the jaws. Index marks or stops may facilitate this.

6.2.2 Thicknesses between 5 mm and 2,5 mm

It is possible to conduct these tests without anti-buckling restraints.

A possible geometry for a flat specimen is shown in Figure 8.

6.2.3 Thicknesses <2,5 mm

The use of anti-buckling restraints may be necessary and may limit the maximum test temperature.

A number of precautions are required to limit the increase in force induced by friction between the restraint and specimen. This friction shall not at any time create a force increase greater than 2 %. The use of a polytetrafluoroethylene (PTFE) film approximately 1 mm thick, for example, offers a partial solution to this problem, as does boron nitride powder as a dry lubricant. Hydrocarbon-based lubricants are not recommended as they may affect the test results.

The frictional forces may vary from one specimen to another. They shall be measured before each test from the force-displacement curves recorded in the elasticity range of the material in tension with and without anti-buckling restraints. An example of an anti-buckling restraint is shown in Figure 11.

6.3 Preparation of specimens

In any fatigue-test program designed to characterize the intrinsic properties of a material, it is important to observe the following recommendations in the preparation of specimens. A deviation from these recommendations is possible if the test program aims to determine the influence of a specific factor (surface treatment, oxidation, etc.) that is incompatible with these recommendations. In all cases, these deviations shall be noted in the test report.

